INDIAN JOURNAL OF
ENGINEERING

19(51), 2022

Comparative Investigation on the Rate of Oil Particles Sedimentation in Stagnant Water Environment

Ozioko FC[1], Ukpaka CP[2], Ikenyiri PN[3]

To Cite:
Ozioko FC, Ukpaka CP, Ikenyiri PN. Comparative Investigation on the Rate of Oil Particles Sedimentation in Stagnant Water Environment. *Indian Journal of Engineering*, 2022, 19(51), 279-293

Author Affiliation:
[1]Research Student: Department of Chemical/Petrochemical Engineering, Rivers State University Port Harcourt, PMB 5080, Rivers State, Nigeria.
[2]Professor: Department of Chemical/Petrochemical Engineering, Rivers State University Port Harcourt, PMB 5080, Rivers State, Nigeria.
Email:chukwuemeka24@yahoo.com
[3]Senior Lecturer: Department of Chemical/Petrochemical Engineering, Rivers State University Port Harcourt, PMB 5080, Rivers State, Nigeria.

Peer-Review History
Received: 27 April 2022
Reviewed & Revised: 29/April/2022 to 04/June/2022
Accepted: 05 June 2022
Published: 09 June 2022

Peer-Review Model
External peer-review was done through double-blind method.

ABSTRACT

The sedimentation of total dissolved solid (TDS) in stagnant water media was studied theoretically by comparing the Ukpaka's model with Newton's Law and Stokes's law through mathematical application. Two tanks of equal capacity were filled to 1.5m^3 volumes of fresh water and salt water respectively. Six control valves were fitted at equal intervals along the tanks' depth, where samples were collected for analysis of physicochemical parameters. Also, the Stokes' and Newton's laws of particles falling under motion in a fluid were modified to study the rate of sedimentation of TDS sediments. The models were compared with rate of sedimentation developed by Ukpaka. Results showed that crude oil has significant impact on the properties of fresh and salt water immediately after pollution. The impact of crude oil was more in the fresh water compared to salt water media. The rate of oil sediment decreased with increased in depth, but the model developed by Ukpaka slightly performed better than the modified Stokes' and Newton's laws, which also compared well with the suspended solid measured from the experiment. However, either of the models can be used to study the rate of oil sediment in stagnant water media.

Key words: Comparative, investigation, rate, oil, particles, sedimentation, stagnant water environment

1. INTRODUCTION

When crude oil spills cause a wide range of difficulties, it is vital to design a prediction model that will help to degrade and salvage impacted areas. Because of the numerous issues caused by crude oil spills, it is vital to design a prediction model that will aid in the degradation of the affected region and the removal of the obnoxious threat. In this paper, a predictive model of crude oil degradation and sedimentation in stagnant water media is developed [1-5]. The influence of dispersion and diffusion of crude oil in stagnant water media is also studied on overall degradation. Consequently, the breakup of the oil and its transport to the water column in addition to the depth of its diffusion are equally the focus of the study [6-8].

Hydrocarbon pollution as a result of petrochemical sector activities is one of today's main environmental issues. Accidental discharges of petroleum products are a major environmental problem [9]. Hydrocarbon components have been identified as Cacinogens and neurotoxic organic pollutants [10]. Removing hydrocarbons from contaminated areas via mechanical and chemical methods is generally futile and expensive [11]. These contaminated locations might benefit from bioremediation since it's cost-effective and can convert organic toxins into carbon dioxide, water, inorganic chemicals and cell protein or break down complex organic compounds into simpler ones by biological agents such as microorganisms [12-16]. A more accurate predictive model must take into account factors such as sedimentation and spreading, which are functions of physical properties such as depth and time in the aquatic environment, as well as oil quality and quantity when developing remediation procedures in order to increase remediation efficiency [17-20].

The aim of this research work is to examine the changes in concentration and sedimentation rate of crude oil in stagnant water media with respect to position and time due to determining factors such as diffusion, dispersion and microbial actions [21-23].

2. MATERIALS AND METHODS

Rate of Oil Particles Sedimentation down the Column

The rate of oil particle settling down the column of the stagnant water was studied using a model. First, a general expression by Ukpaka [18] on sedimentation of suspended solid particle, as influenced by continuous discharge of waste in pond system, was modified based on the Stokes' and Newton's laws of particles falling into fluid system.

According to Ukpaka [18], the rate of sedimentation is determined as:

$$R_s = \frac{v_s}{z} C_{ss} \tag{1}$$

After several mathematical relations with respect to influential parameters, Ukpaka [18] finally expressed the rate of sedimentation as:

$$R_s = \left[U - \exp\left(\frac{1}{gS_o z} \cdot \frac{v_s^2}{1 - v_s} \right) \right] \frac{v_s}{z} \tag{2}$$

where:

$R_s =$ Rate of settling of particle (mg/l.day)

$U =$ Rate of momentum transfer (kg.m/day)

$C_{ss} =$ Concentration of suspended solids (mg/l)

$g =$ Acceleration due to gravity (m/s^2)

$S_o =$ Below the surface water slope (-)

$z =$ Height of sample point from water surface (m)

$v_z =$ Settling velocity (m/s)

In this study, we modified equation (1) with the assumption that the oil particle falling in the stagnant water obeyed two laws: Stokes' and Newton's laws.

Rate of Sedimentation Based on Stokes' Law

The settling velocity in this case, was developed based on the concept of Stokes' law, which is expressed as:

$$v_s \propto gD_p^2 \left(\frac{\rho_p - \rho_f}{18\mu} \right) \tag{3}$$

Removing the proportionality, we obtain as follows:

$$v_s = k_F g D_p^2 \left(\frac{\rho_p - \rho_f}{18\mu} \right) \tag{4}$$

Since the oil volume is measurable, the particle diameter, D_p was expressed in terms of oil particle volume. Thus, the oil particle volume is assumed to be spherical in shape. The volume of sphere is expressed as:

$$V = \frac{\pi D_p^3}{6} \tag{5}$$

Hence, in terms of particle diameter, equation (5) can be stated as:

$$D_p = \left(\frac{6V}{\pi} \right)^{1/3} \tag{6}$$

Substituting equation (6) into (3) gives:

$$v_s = k_F g \left(\frac{6V}{\pi} \right)^{2/3} \left(\frac{\rho_p - \rho_f}{18\mu} \right) \tag{7}$$

After simplification and substitution of equation (7) into (1), we obtained:

$$R_s = K_F g V^{2/3} \left(\frac{\rho_p - \rho_f}{18\mu} \right) \frac{C_{TSS}}{z} \tag{8}$$

Rate of Sedimentation Based on Newton's Law

Expressing the settling velocity in terms of Newton's law of particle falling in a fluid, we modified the settling velocity as:

$$v_s \propto \left[g D_p \left(\frac{\rho_p - \rho_f}{\rho_f} \right) \right]^{1/2} \tag{9}$$

Removing the proportionality, we obtain as follows:

$$v_s = k_F^* \left[g D_p \left(\frac{\rho_p - \rho_f}{\rho_f} \right) \right]^{1/2} \tag{10}$$

Unlike Stokes's law, the particle settling velocity does not depend on the fluid viscosity in the Newton's law. Again, in terms of particle diameter, Equations (5) and (6) are combined and substituted into Equation (3.56) to give:

$$v_s = k_F^* \left(\frac{6V}{\pi} \right)^{1/6} \left[\left(\frac{\rho_p - \rho_f}{\rho_f} \right) g \right]^{1/2} \tag{11}$$

Again, simplification and substitution of equation (11) into (1) gives:

$$R_s = K_F^* V^{1/6} \left[\left(\frac{\rho_p - \rho_f}{\rho_f} \right) g \right]^{1/2} \frac{C_{TSS}}{z} \tag{12}$$

where:

R_s = Particle settling rate (mg/l.day)

C_{TPH} = TPH concentration (mg/l)

v_s = Settling velocity (m/s)

z = Height of sample point from water surface (m)

V = Volume of oil (m^3)

D_p = Oil particle diameter (m)

ρ_p = Oil particle density (kg/m^3)

ρ_f = Fluid density (kg/m^3)

μ = Viscosity of fluid (kg/m.s)

g = Acceleration due to gravity (m/s^2)

K_F and K_F^* = Constants of settling velocity of modified Stokes and Newton's equations

3. RESULTS AND DISCUSSION

The rate of sedimentation TPH content in the water were studied using mathematical models.

Rate of Sedimentation along the Tank Depth

The rate of oil sediment in stagnant fresh water and salt water media models was studied in terms of the measured total suspended solids (TSS). The rate of sedimentation over the investigation period for the three models was compared as shown in Figures 1 to 14 for the various weeks of the analysis.

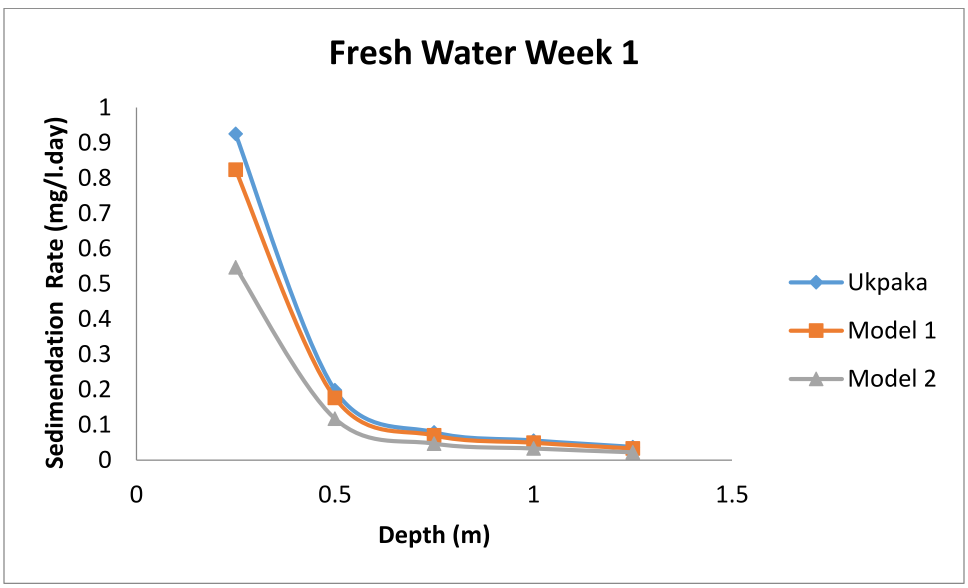

Figure 1: Rate of Sedimentation in Fresh Water along the Tank Depth for Week 1

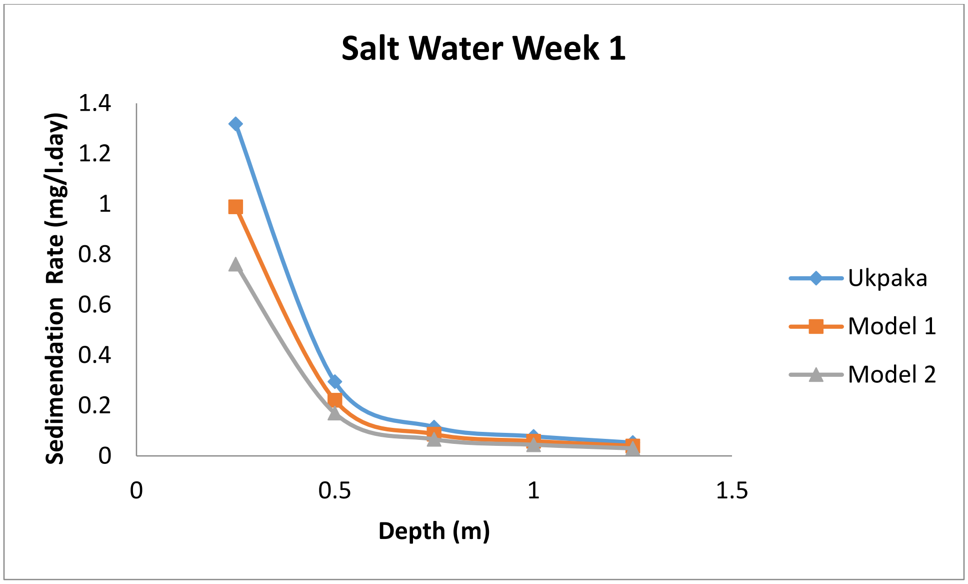

Figure 2: Rate of Sedimentation in Salt Water along the Tank Depth for Week 1

Figures 1 and 2 showed the rate of sedimentation of suspended solids in stagnant fresh water and salt water polluted by crude oil, respectively at first week (day 1). From the profiles, the rate of sedimentation decreased with increase in depth. The results obtained within the first week of investigation for fresh water showed that the rate of sedimentation obtained from Ukpaka model decreased from 0.926mg/l.day at 0.25m depth to 0.037mg/l.day at 1.25m depth, while the rate of sedimentation obtained from the modified Stokes' law (model 1) and Newton's law (model 2) decreased from 0.824mg/l.day at 0.25m depth to 0.033mg/l.day at 1.25m depth and 0.547mg/l.day at 0.25m depth to 0.022mg/l.day at 1.25m depth respectively.

Similarly, in salt water, the rate of sedimentation obtained from Ukpaka model decreased from 1.319mg/l.day at 0.25m depth to 0.054mg/l.day at 1.25m depth, while the rate of sedimentation obtained from the modified Stokes' law (model 1) and Newton's law (model 2) decreased from 0.989mg/l.day at 0.25m depth to 0.040mg/l.day at 1.25m depth and 0.763ppm/day at 0.25m depth to 0.031mg/l.day at 1.25m depth respectively. Comprehensive result for fresh and salt water media is shown in Table 17B of Appendix.

The model modified using Newton's law (model 2) has the lowest rate of sedimentation, while the model developed by Ukpaka has the highest rate of sedimentation. Despite the slight difference in the model performances, the rate of sedimentation obtained from the models implies that either of the models can be used to study the rate of oil sediment in stagnant water media. The trends for rate of sedimentation obtained in this study agreed with the work of Ukpaka [18].

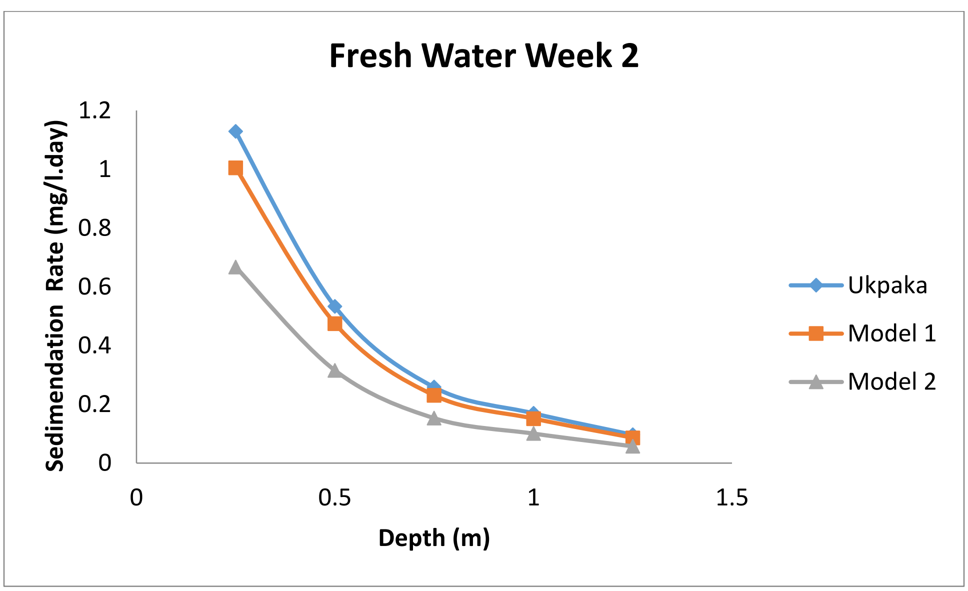

Figure 3: Rate of Sedimentation in Fresh Water along the Tank Depth for Week 2

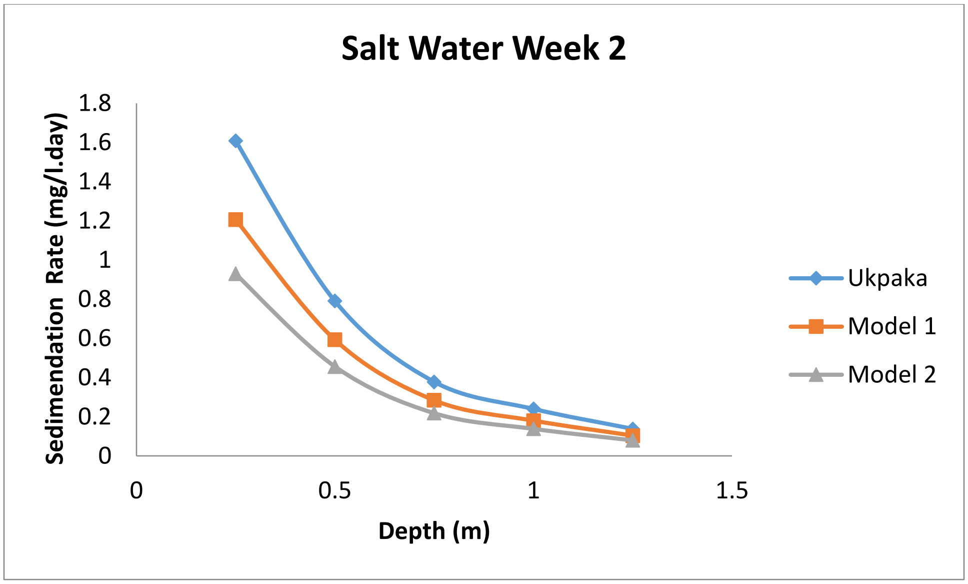

Figure 4: Rate of Sedimentation in Salt Water along the Tank Depth for Week 2

Figures 3 and 4 showed the rate of sedimentation of suspended solids in crude oil polluted stagnant fresh water and salt water, respectively for week 2 (Day 14). The rate of sedimentation decreased with increase in depth. In fresh water, the rate of sedimentation obtained from Ukpaka model at Day 14 decreased from 1.129mg/l.day at 0.25m depth to 0.096mg/l.day at 1.25m depth, while those obtained from the modified Stokes' law (model 1) and Newton's law (model 2) decreased from 1.005mg/l.day at 0.25m depth to 0.104mg/l.day at 1.25m depth and 0.668mg/l.day at 0.25m depth to 0.080mg/l.day at 1.25m depth respectively.

Similarly, in salt water, the rate of sedimentation from Ukpaka model decreased from 1.609mg/l.day at 0.25m depth to 0.139mg/l.day at 1.25m depth, while those obtained from the modified Stokes' law (model 1) and Newton's law (model 2) decreased from 1.207mg/l.day at 0.25m depth to 0.104mg/l.day at 1.25m depth and 0.931mg/l.day at 0.25m depth to 0.080mg/l.day at 1.25m depth respectively. Comprehensive results for fresh and salt water media are shown in Table 18B of Appendix. Again, the model modified using Newton's law has the lowest rate of sedimentation, followed by the modified Stokes' law and highest in Ukpaka model.

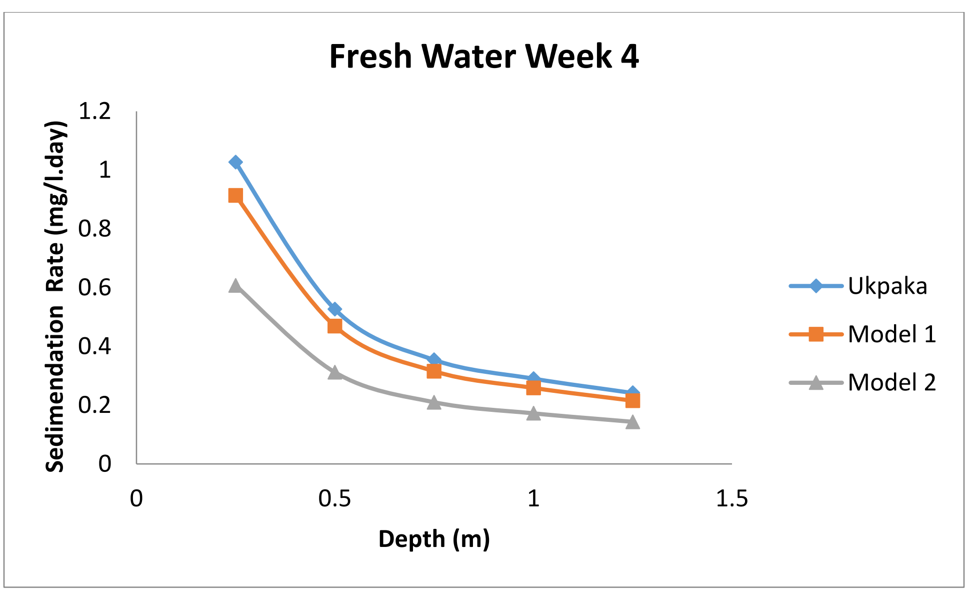

Figure 5: Rate of Sedimentation in Fresh Water along the Tank Depth for Week 4

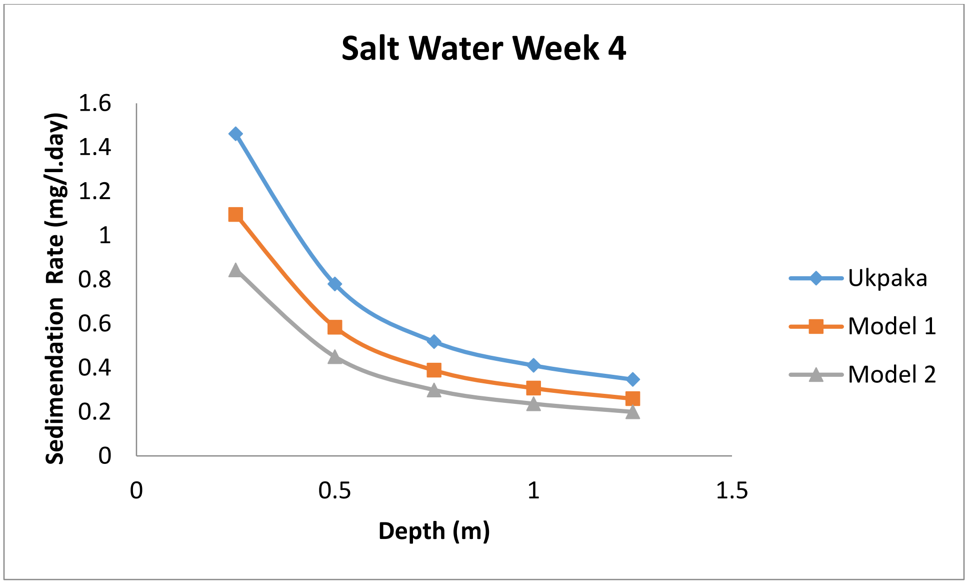

Figure 6: Rate of Sedimentation in Salt Water along the Tank Depth for Week 4

Figures 5 and 6 showed the rate of sedimentation of suspended solids in crude oil polluted stagnant fresh water and salt water, respectively for week 4. The rate of sedimentation also decreased with increase in depth at week 4 (Day 28). In fresh water, the rate of sedimentation obtained from Ukpaka model at Day 28 decreased from 1.026mg/l.day at 0.25m depth to 0.241mg/l.day at 1.25m depth, while those obtained from the modified Stokes' law and Newton's law decreased from 0.913mg/l.day at 0.25m depth to 0.215mg/l.day at 1.25m depth and 0.607mg/l.day at 0.25m depth to 0.143pmm/day at 1.25m depth respectively.

For salt water at day 28, the rate of sedimentation from Ukpaka model decreased from 1.462mg/l.day at 0.25m depth to 0.348mg/l.day at 1.25m depth, while those obtained from the modified Stokes' law and Newton's law decreased from 1.097mg/l.day at 0.25m depth to 0.143mg/l.day at 1.25m depth and 0.845mg/l.day at 0.25m depth to 0.201mg/l.day at 1.25m depth respectively. Comprehensive result for fresh and salt water media is shown in Table 19B of Appendix. Again, the model modified using Newton's law has the lowest rate of sedimentation, followed by the modified Stokes' law and highest in Ukpaka.

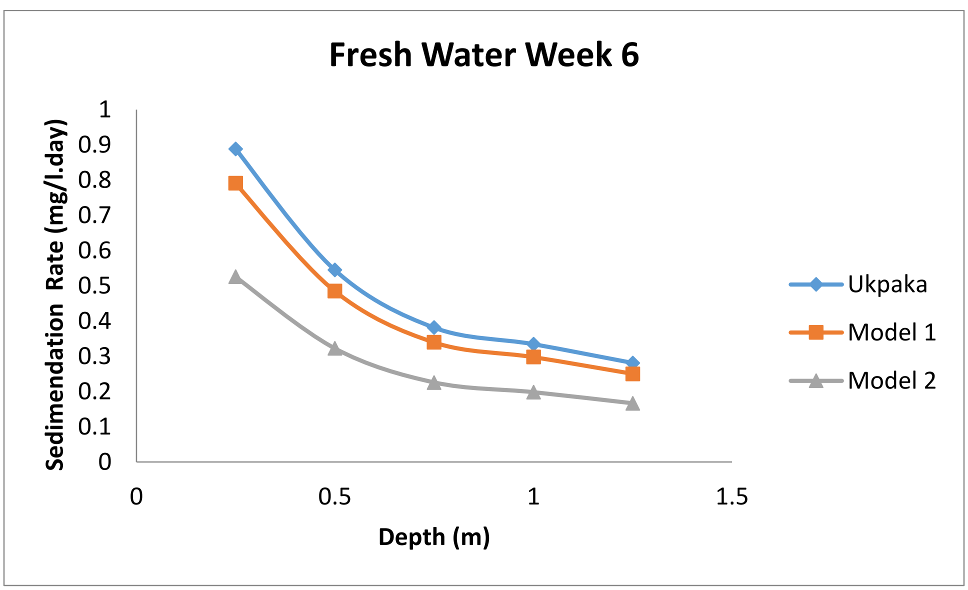

Figure 7: Rate of Sedimentation in Fresh Water along the Tank Depth for Week 6

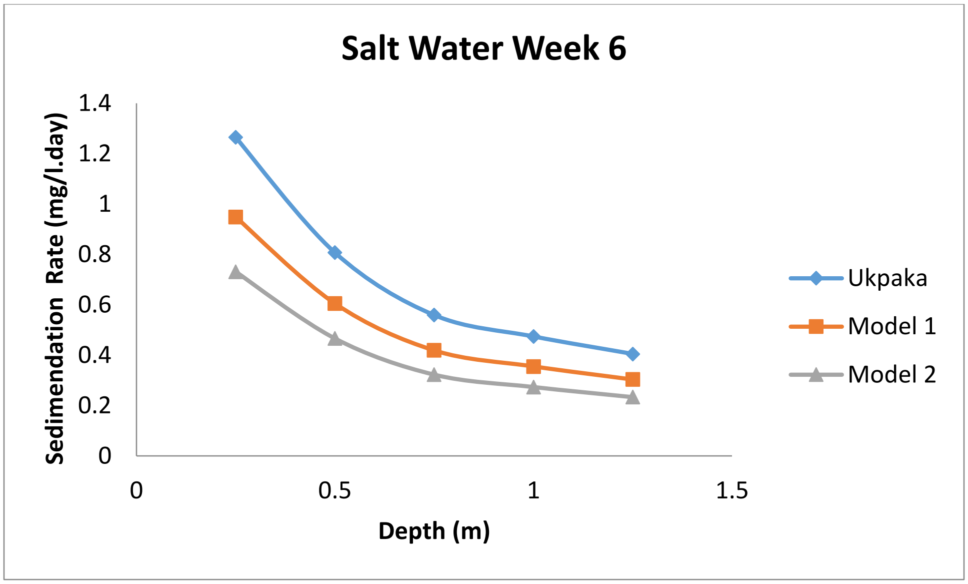

Figure 8: Rate of Sedimentation in Salt Water along the Tank Depth for Week 6

Figures 7 and 8 showed the rate of sedimentation of suspended solids in crude oil polluted stagnant fresh water and salt water, respectively at week 6 (Day 42). The rate of sedimentation also decreased with increase in depth at week 6. In fresh water, the rate of sedimentation obtained from Ukpaka model at Day 42 decreased from 0.888mg/l.day at 0.25m depth to 0.281mg/l.day at 1.25m depth, while those obtained from the modified Stokes' law (model 1) and Newton's law (model 2) decreased from 0.791mg/l.day at 0.25m depth to 0.250mg/l.day at 1.25m depth and 0.525mg/l.day at 0.25m depth to 0.166mg/l.day at 1.25m depth respectively.

Similarly, in salt water, the rate of sedimentation from Ukpaka model at Day 42 decreased from 1.266mg/l.day at 0.25m depth to 0.405mg/l.day at 1.25m depth, while those obtained from the modified Stokes' law (model 1) and Newton's law (model 2) decreased from 0.950mg/l.day at 0.25m depth to 0.304mg/l.day at 1.25m depth and 0.732mg/l.day at 0.25m depth to 0.234mg/l.day at 1.25m depth respectively. Comprehensive result for fresh and salt water media is shown in Table 20B of Appendix. Again, the model modified using Newton's law has the lowest rate of sedimentation, followed by the modified Stokes' law and highest in Ukpaka.

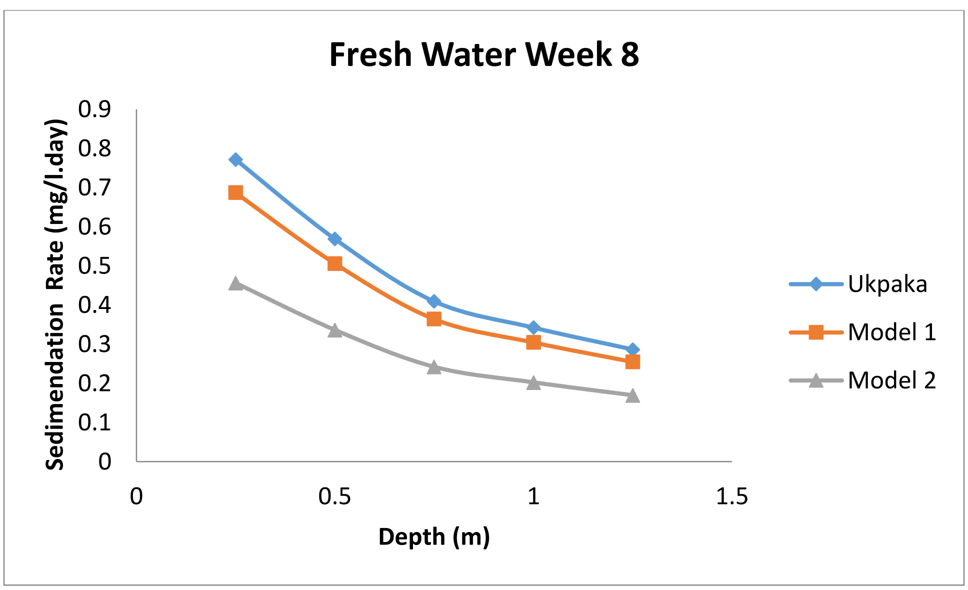

Figure 9: Rate of Sedimentation in Fresh Water along the Tank Depth for Week 8

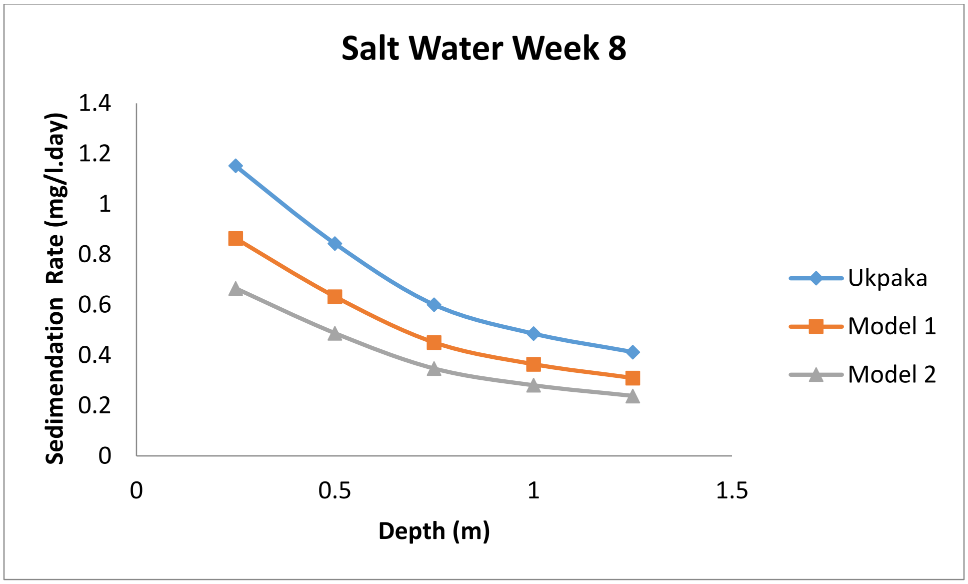

Figure 10: Rate of Sedimentation in Salt Water along the Tank Depth for Week 8

Figures 9 and 10 showed the rate of sedimentation of suspended solids in crude oil polluted stagnant fresh water and salt water, respectively for week 8. The rate of sedimentation also decreased with increase in depth at week 8 (Day 56). In fresh water, the rate of sedimentation obtained from Ukpaka model at Day 56 decreased from 0.772mg/l.day at 0.25m depth to 0.287mg/l.day at 1.25m depth, while those obtained from the modified Stokes' law (model 1) and Newton's law (model 2) decreased from 0.688mg/l.day at 0.25m depth to 0.255mg/l.day at 1.25m depth and 0.457mg/l.day at 0.25m depth to 0.170mg/l.day at 1.25m depth respectively.

Similarly, in salt water, the rate of sedimentation from Ukpaka model decreased from 1.152mg/l.day at 0.25m depth to 0.413mg/l.day at 1.25m depth, while those obtained from the modified Stokes' law (model 1) and Newton's law (model 2) decreased from 0.864mg/l.day at 0.25m depth to 0.310mg/l.day at 1.25m depth and 0.666mg/l.day at 0.25m depth to 0.239mg/l.day at 1.25m depth respectively. Comprehensive result for fresh and salt water media is shown in Table 21B of Appendix. Again, the model modified using Newton's law has the lowest rate of sedimentation, followed by the modified Stokes' law and highest in Ukpaka.

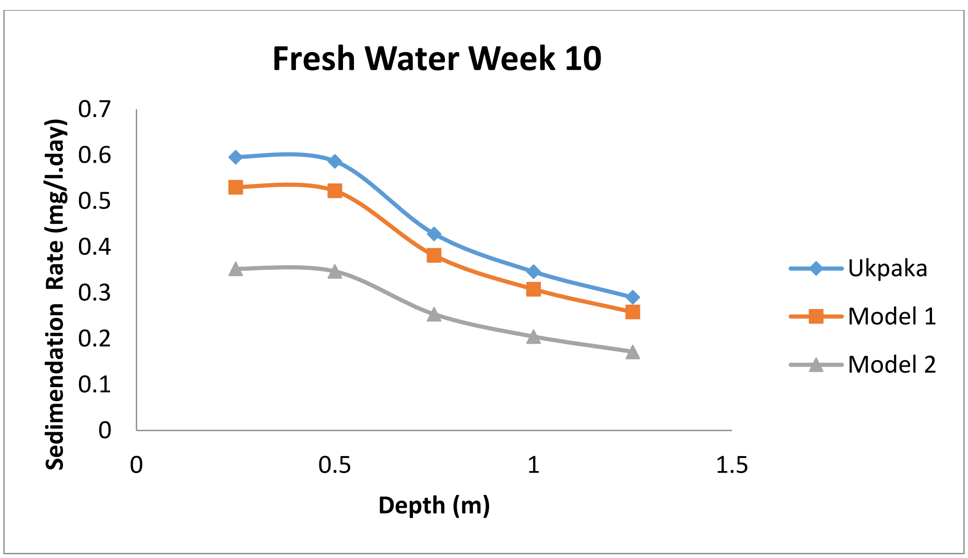

Figure 11: Rate of Sedimentation in Fresh Water along the Tank Depth for Week 10

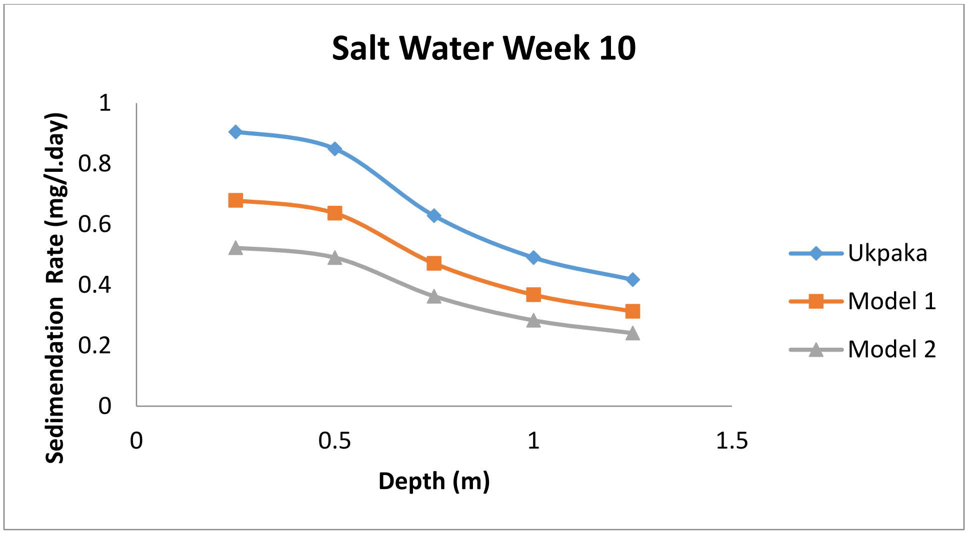

Figure 12: Rate of Sedimentation in Salt Water along the Tank Depth for Week 10

Figures 11 and 12 showed the rate of sedimentation of suspended solids in crude oil polluted stagnant fresh water and salt water, respectively for week 10. The rate of sedimentation also decreased with increase in depth at week 10 (Day 70). In fresh water, the rate of sedimentation obtained from Ukpaka model at Day 70 decreased from 0.596mg/l.day at 0.25m depth to 0.290mg/l.day at 1.25m depth, while the rate obtained from the modified Stokes' law and Newton's law decreased from 0.531mg/l.day at 0.25m depth to 0.258mg/l.day at 1.25m depth and 0.352mg/l.day at 0.25m depth to 0172mg/l.day at 1.25m depth respectively.

Similarly, in salt water, the rate of sedimentation from Ukpaka model decreased from 0.905mg/l.day at 0.25m depth to 0.418mg/l.day at 1.25m depth, while the rate obtained from the modified Stokes' law and Newton's law decreased from 0.679mg/l.day at 0.25m depth to 0.313mg/l.day at 1.25m depth and 0.523mg/l.day at 0.25m depth to 0.242mg/l.day at 1.25m depth respectively. Comprehensive result for fresh and salt water media is shown in Table 22B of Appendix. Again, the model modified using Newton's law has the lowest rate of sedimentation, followed by the modified Stokes' law and highest in Ukpaka.

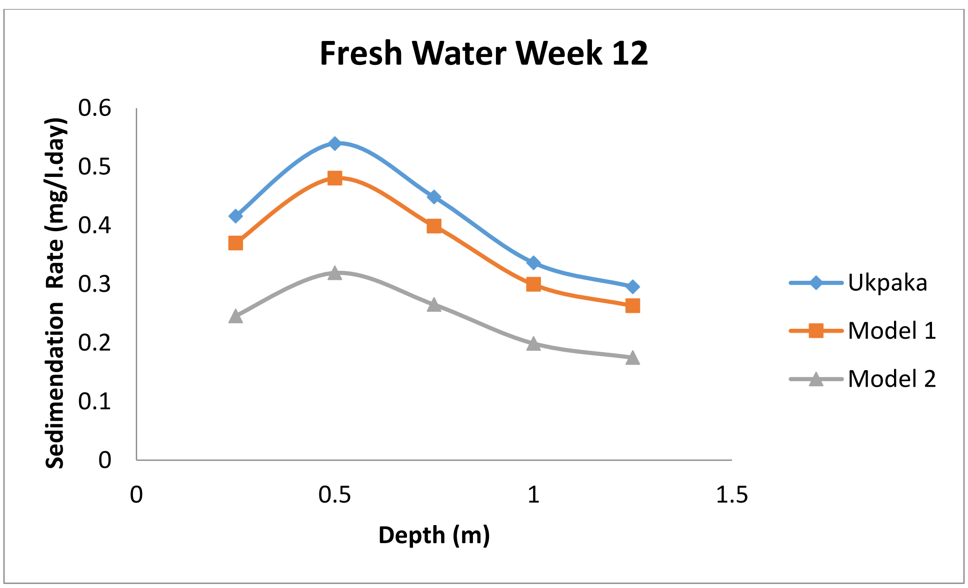

Figure 13: Rate of Sedimentation in Fresh Water along the Tank Depth for Week 12

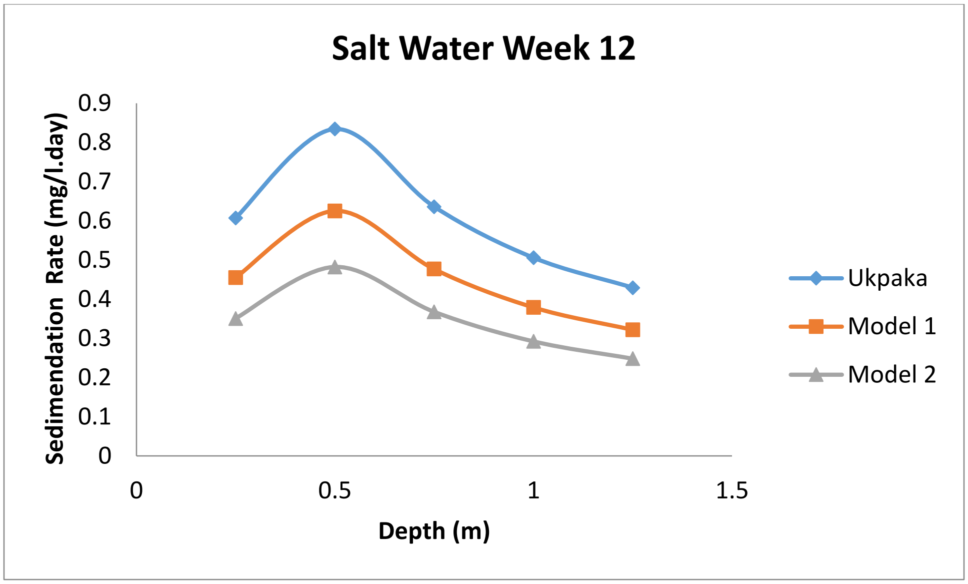

Figure 14: Rate of Sedimentation in Salt Water along the Tank Depth for Week 12

Figures 13 and 14 showed the rate of sedimentation of suspended solids in crude oil polluted stagnant fresh water and salt water, respectively for week 12. The rate of sedimentation also decreased with increase in depth at week 12 (Day 84). In fresh water, the rate of sedimentation obtained from Ukpaka model at Day 84 decreased from 0.416mg/l.day at 0.25m depth to 0.295mg/l.day at 1.25m depth, while the rate obtained from the modified Stokes' law and Newton's law decreased from 0.370mg/l.day at 0.25m depth to 0.263mg/l.day at 1.25m depth and 0.246mg/l.day at 0.25m depth to 0.175mg/l.day at 1.25m depth respectively.

Similarly, in salt water, the rate of sedimentation from Ukpaka model decreased from 0.607mg/l.day at 0.25m depth to 0.430mg/l.day at 1.25m depth, while those obtained from the modified Stokes' law and Newton's law decreased from 0.456mg/l.day at 0.25m depth to 0.322mg/l.day at 1.25m depth and 0.351mg/l.day at 0.25m depth to 0.248mg/l.day at 1.25m depth respectively. Comprehensive results for fresh and salt water media are shown in Table 23B of Appendix. Again, the model modified using Newton's law has the lowest rate of sedimentation, followed by the modified Stokes' law and highest in Ukpaka.

Generally, rate of sedimentation decreased with increase in depth and time. This implied that rate at which suspended solids entrained in crude oil settled on the base stagnant water media is highly dependent on depth at specified time. This agreed with earlier observation by Ukpaka while studying the effect of continuous discharge of wastewater on the rate of suspended solids in pond system (Ukpaka, [19]).

4. CONCLUSION

The conclusion of the research are demonstrated below as:

a. The rate of oil sediment in stagnant water media can be studied using either of the modified Newton's law, Stokes' law or the sedimentation model developed by Ukpaka [18].
b. Crude oil significantly altered the physicochemical properties of stagnant water, even at depths below the surface.
c. Crude oil pollution in the stagnant fresh and salt water media aided the gradual growth of bacteria, which became rapid within 70 to 84 days. Hence, the bacteria identified can be isolated, cultured and utilise for biodegradation of hydrocarbon in stagnant water media.
d. The rate of Total Petroleum Hydrocarbon (TPH) reduction over time was higher in salt water than fresh water media.

Appendix

Table 1: Rate of Sedimentation (mg/l.day) at Week 1

H (m)	Ukpaka		Stokes' Law		Newton's Law	
	FW	SW	FW	SW	FW	SW
0.25	0.9255	1.3190	0.8239	0.9892	0.5474	0.7625
0.5	0.1988	0.2948	0.1770	0.2211	0.1176	0.1705

0.75	0.0787	0.1155	0.0701	0.0866	0.0466	0.0668
1	0.0553	0.0785	0.0493	0.0589	0.0327	0.0454
1.25	0.0371	0.0535	0.0330	0.0401	0.0220	0.0309

Table 2: Rate of Sedimentation (mg/l.day) at Week 2

H (m)	Ukpaka		Stokes' Law		Newton's Law	
	FW	SW	FW	SW	FW	SW
0.25	1.1293	1.6094	1.0053	1.2071	0.6679	0.9305
0.5	0.5334	0.7911	0.4749	0.5933	0.3155	0.4573
0.75	0.2583	0.3790	0.2300	0.2843	0.1528	0.2191
1	0.1695	0.2405	0.1509	0.1804	0.1003	0.1391
1.25	0.0963	0.1388	0.0857	0.1041	0.0570	0.0802

Table 3: Rate of Sedimentation (mg/l.day) at Week 4

H (m)	Ukpaka		Stokes' Law		Newton's Law	
	FW	SW	FW	SW	FW	SW
0.25	1.0260	1.4622	0.9134	1.0966	0.6068	0.8453
0.5	0.5262	0.7804	0.4685	0.5853	0.3113	0.4512
0.75	0.3539	0.5192	0.3150	0.3894	0.2093	0.3002
1	0.2899	0.4114	0.2581	0.3086	0.1715	0.2378
1.25	0.2412	0.3475	0.2147	0.2606	0.1426	0.2009

Table 4: Rate of Sedimentation (mg/l.day) at Week 6

H (m)	Ukpaka		Stokes' Law		Newton's Law	
	FW	SW	FW	SW	FW	SW
0.25	0.8883	1.2659	0.7908	0.9494	0.5254	0.7319
0.5	0.5446	0.8076	0.4848	0.6057	0.3221	0.4669
0.75	0.3812	0.5593	0.3394	0.4195	0.2255	0.3234
1	0.3343	0.4744	0.2976	0.3558	0.1977	0.2743
1.25	0.2811	0.4050	0.2502	0.3037	0.1662	0.2341

Table 5: Rate of Sedimentation (mg/l.day) at Week 8

H (m)	Ukpaka		Stokes' Law		Newton's Law	
	FW	SW	FW	SW	FW	SW
0.25	0.7722	1.1517	0.6875	0.8638	0.4567	0.6659
0.5	0.5689	0.8437	0.5065	0.6327	0.3365	0.4877
0.75	0.4094	0.6007	0.3645	0.4506	0.2422	0.3473
1	0.3424	0.4858	0.3048	0.3644	0.2025	0.2809
1.25	0.2866	0.4130	0.2552	0.3097	0.1695	0.2387

Table 6: Rate of Sedimentation (mg/l.day) at Week 10

H (m)	Ukpaka		Stokes' Law		Newton's Law	
	FW	SW	FW	SW	FW	SW
0.25	0.5958	0.9054	0.5305	0.6791	0.3524	0.5235
0.5	0.5866	0.8494	0.5222	0.6370	0.3469	0.4911

0.75	0.4284	0.6286	0.3814	0.4715	0.2534	0.3634
1	0.3460	0.4910	0.3080	0.3682	0.2047	0.2838
1.25	0.2901	0.4179	0.2582	0.3134	0.1716	0.2416

Table 7: Rate of Sedimentation (mg/l.day) at Week 12

H (m)	Ukpaka		Stokes' Law		Newton's Law	
	FW	SW	FW	SW	FW	SW
0.25	0.4156	0.6073	0.3700	0.4555	0.2458	0.3511
0.5	0.5396	0.8344	0.4804	0.6258	0.3192	0.4824
0.75	0.4482	0.6363	0.3990	0.4772	0.2651	0.3679
1	0.3363	0.5061	0.2994	0.3796	0.1989	0.2926
1.25	0.2953	0.4296	0.2629	0.3222	0.1747	0.2484

Table 8: Total Dissolved Solids (TDS) Measurement in Fresh Water

Time (Days)	TDS (mg/l)					
	Pt 1	Pt 2	pt 3	Pt 4	Pt 5	Pt 6
1	120.08	118.9	118.74	116.85	115.93	113.7
14	113.04	113.06	113.08	113.1	113.11	113.14
28	90.71	96.96	106.41	106.8	107	113.02
42	90.21	96.18	98.51	101.86	103.72	87.53
56	84.8	84.83	85.15	85.28	85.3	85.33
70	83.84	84.09	84.12	84.14	84.16	84.2
84	83.63	83.7	83.72	83.75	83.79	83.8

Table 9: Total Dissolved Solids (TDS) Measurement in Salt Water

Time (Days)	TDS (mg/l)					
	Pt 1	Pt 2	pt 3	Pt 4	Pt 5	Pt 6
1	132.2	130.06	129.5	126	125.8	124.11
14	194.11	198.06	198.5	198.91	142.23	176.18
28	192.4	192.43	192.6	193.12	193.45	193.5
42	190.4	190.75	191.08	191.48	191.62	191.74
56	188.31	188.6	188.9	190.12	190.15	190.25
70	186.7	187.13	187.38	187.72	188.05	188.2
84	183.9	184.6	185.1	185.52	186.6	186.66

Table 10: Input Data for Model Simulation

Parameter	Value	Reference
Diffusion coefficient, D (m^2/s) in z-direction	$3.4928 \times 10^{-5} - 1.7464 \times 10^{-4}$	This work
Diffusion coefficient, D (m^2/s) in x-direction	$3.5645 \times 10^{-6} - 1.7802 \times 10^{-5}$	This work
Water depth, d (m)	1.5	This work
Height of sample point from water surface, z (m)	0.25 – 1.25	This work
Karman's constant, k_0 (-)	114.52	Zhi-Wei *et al.*

		(2000)
First Order Rate Constant, k_d (day^{-1})	FW: 0.0034 SW: 0.00213	This work
Maximum rate constant, U_m (mg/l)	FW: 24.1908 SW: 10.4564	This work
Mono constant, K_m (mg/l)	FW: 12716.43 SW: 8239.27	This work
Rate of momentum transfer, U (kg.m/day)	1.0	Ukpaka (2011)
Acceleration due to gravity , g (m/s^2)	9.81	
Below the surface water slope, S_o (-)	5.6254×10^{-4}	Ukpaka (2011)
K_F in modified Stokes' equation (-)	FW: 1.0625×10^{-11} SW: 2.8407×10^{-2}	This work
K_F^* in modified Newton's equation (-)	FW: 1.7741×10^{-8} SW: 2.9988×10^{-8}	This work
v_s in modified Stokes' equation (m/s)	FW: 7.3×10^{-4} SW: 9.6×10^{-4}	This work
v_s in modified Newton's equation (m/s)	FW: 4.85×10^{-4} SW: 6.68×10^{-4}	This work
v_s in Ukpaka model (m/s)	FW: 8.20×10^{-4} SW: 1.28×10^{-4}	This work
Volume of oil, V (m^3)	2.5×10^{-4}	This work
Oil particle density ρ_p (kg/m^3)	1162	This work
Fluid density, ρ_f (kg/m^3)	1000	This work
Viscosity of fluid, μ (kg/m.s)	2.41×10^{-3}	This work

NB: FW = Fresh Water and SW = Salt Water

Funding

This study has not received any external funding.

Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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